THE ROLE OF DEEP CONVECTION IN MOISTENING THE INNER CORE REGIONS OF DEVELOPING TROPICAL CYCLONES: EVIDENCE FROM GRIP 2010

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1. Introduction

The 2010 NASA Genesis and Rapid Intensification Processes (GRIP) campaign (Braun et al. 2012), conducted concurrently with the NSF/NCAR Pre-Depression Investigation of Cloud Systems in the Tropics (PREDICT; Montgomery et al. 2012) and NOAA Intensity Forecast Experiment (IFEX), provides an unprecedented high spatial and temporal resolution dataset of tropical cyclogenesis events. In-situ data from coincident and consecutive flights into developing Karl and Matthew, combined with conventional geostationary infrared and overpasses of passive microwave instruments, offers the best opportunity to date to examine, in detail, the pre-genesis wind field at multiple levels, deep convection, and the time evolution of the thermodynamic properties of the developing inner core. The goal of this paper is to describe the relationship between deep convective episodes in pre-Karl and pre-Matthew and the thermodynamic characteristics of the inner core, as well as offer insight into what ultimately determines the fate of disturbances with apparent genesis potential.

2. Data and Methodology

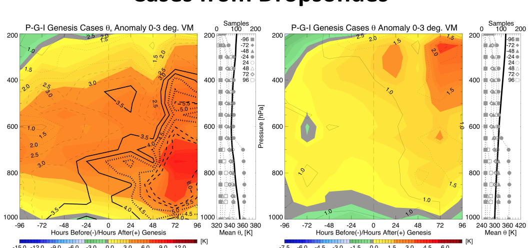
○ For each disturbance, the "center" is defined by the vorticity maximum (VM) manually tracked in the 1x1° NCEP FNL model analysis. While 925, 700 and 600 hPa are also tracked, only 850 hPa is used in the analysis
○ "Inner-core" is defined as 0-3° from the 850 hPa VM center
○ Genesis defined by TD classification by NHC

○ In-situ:
Dropsonde data from PREDICT-GRIP-IFEX (PGI) and USAF C-130s are interpolated to 17 pressure levels and combined into a single dataset

○ Satellite:
- Infrared (IR) every 30 min. at 3 km resolution
- Passive Microwave (PMW) T_b from AMSR-E, TRMM TMI, SSM-I(S) 15, 16, 17
- Derived Total Precipitable Water (TPW) [REMSS] from AMSR-E, TMI, SSM-I(S)
- AIRS
- TRMM merged-IR rain rate (3B42)

* Given that not all swaths from PMW platforms completely cover the inner core, the fractional coverage of data within 3° is computed for each swath. To be considered for the analysis, the swath must contain data within 0.5° of the VM center; this ensures that for most overpasses included, the fractional coverage of data within the inner core is at least 40%. For AIRS, the fractional coverage may be lower since data in raining areas must be excluded.

3. Thermodynamic Evolution of PGI Genesis Cases from Dropsondes



Composite θ_e (left) and θ (right) anomaly of all dropsondes within 3° of the 850 hPa VM center for all PGI genesis cases; black contours are standard deviation

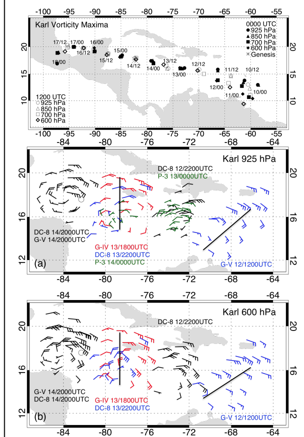
○ The mean midlevel θ_e of developing tropical cyclones is *higher* than that of the surrounding environment, and *increases slightly* each day, while the low-levels exhibit *little increase* until after formation

○ The warm core is developing at mid- to upper-levels (above 600 hPa) as many as *3 days* before genesis

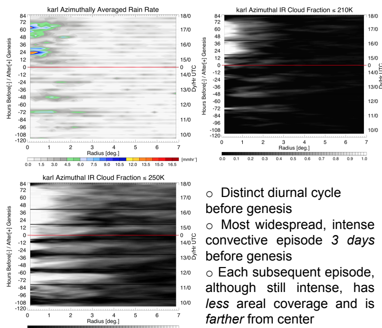
○ Persistent *cool anomaly* at low-levels

○ Given the relatively small magnitude of the θ anomaly compared to θ_e, the positive, increasing (albeit slowly) θ_e anomaly at mid-levels is attributed to an increase in moisture content

4. Time Evolution of Pre-Karl



Flights are separated by color & locations are time-space adjusted, based on the zonal phase speed, to time indicated



○ Distinct diurnal cycle before genesis
○ Most widespread, intense convective episode *3 days* before genesis
○ Each subsequent episode, although still intense, has *less* areal coverage and is *farther* from center

○ No low or midlevel circulation present prior to 13 Sept.
○ Prior to 13 Sept., the wave exhibited a SW-NE horizontal tilt

○ When the winds become more symmetric on 13 Sept., wave vorticity is predominately from curvature, rather than from shear, and thus *more favorable for formation*

KEY:
Diurnal minimum | Diurnal maximum (IR frac. ≤ 210K)
Symbol size is fraction of swath data coverage within inner core (larger the symbol, greater fraction/confidence)

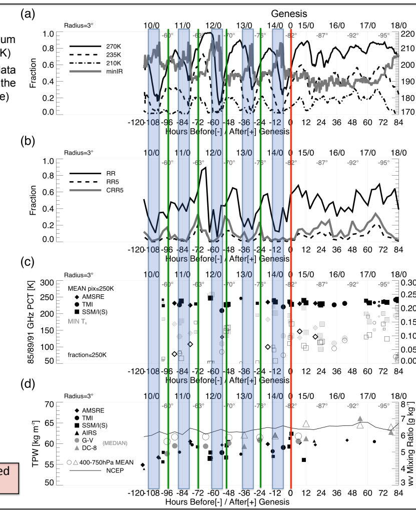
○ Areal coverage of cold cloud *decreases* slightly each day before genesis

○ Raining fraction *decreases* slightly each day before genesis

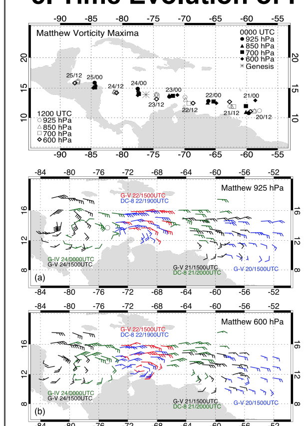
○ *Greatest* fractional coverage of low PCT is *3 days* prior; episode *just prior* to genesis day has *least* areal coverage

○ *Slight increase in midlevel wvMR* prior to genesis; TPW shows *slight* increasing trend

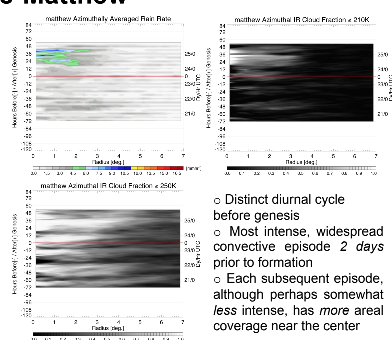
Karl thermodynamically primed up to 4 days before formation



5. Time Evolution of Pre-Matthew



Flights are separated by color & locations are time-space adjusted, based on the zonal phase speed, to time indicated



○ Distinct diurnal cycle before genesis
○ Most intense, widespread convective episode *2 days* prior to formation
○ Each subsequent episode, although perhaps somewhat *less* intense, has *more* areal coverage near the center

○ Some resemblance to Karl, except *clear midlevel circulation* one day before genesis

○ When the winds became more symmetric on 22 Sept., wave vorticity is predominately from curvature, rather than from shear, and thus *more favorable for formation*

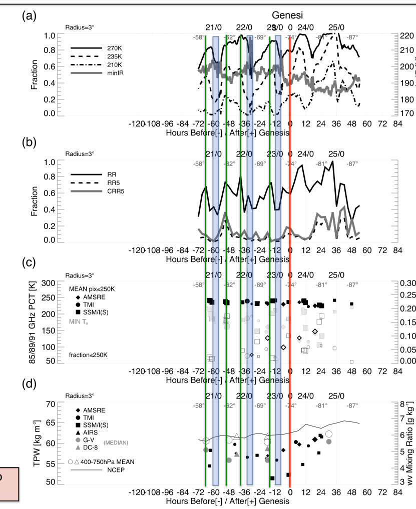
○ No significant difference in areal coverage of cold cloud

○ No significant difference in areal coverage of rainfall; but much less areal coverage of intense rainfall in event prior to genesis; *greater raining fraction during diurnal mins. than Karl*

○ *Most intense burst* (min PCT) is *1 day before*; however fractional area of low PCT is *greatest 2 days prior*

No noticeable increase in midlevel wvMR prior to genesis; TPW shows *no* increasing trend

Matthew thermodynamically primed up to 3 days before formation



6. Summary & Conclusions

○ The inner core of developing disturbances exhibit positive θ and moisture anomalies prior to formation; moisture increases slightly at mid-levels, while the warm core at upper-levels intensifies as many as 3 days prior to genesis

Pre-Karl:
○ Considering the wave and convective history, and that the inner core is already moist, the formation of Karl seems more closely tied to the wave organization on 13 September, rather than to any distinguishing characteristic of the convection

Pre-Matthew:
○ Similar to Karl, areal coverage of *intense* convection *decreases* in each episode prior to formation of Matthew
○ In contrast to Karl, rainfall is *more persistent* through the diurnal cycle in pre-Matthew
○ Although perhaps less intense than in Karl, rainfall is *closer to the center* in episodes prior to formation of Matthew
○ Are the more "favorable" (persistence, areal coverage, proximity to the center) convective characteristics in pre-Matthew responsible for genesis of the pre-cursor disturbance sooner than Karl? Is the presence of midlevel circulation in pre-Matthew (not observed in pre-Karl) important?

○ **Multiple pathways to tropical cyclogenesis**
○ Once the inner 3° is moist, diurnal convection does little to further increase inner core moisture in the *pre-cursor* disturbance (i.e., there is little evidence to support 'progressive moistening')
○ Intense convection is not sufficient for formation; *is it even necessary?*
○ For genesis, wave vorticity must be predominately from *curvature*
○ VM & pouch must be *vertically aligned* (Davis & Ahijevych, 2012)

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